NUCOMM INC.
MICROWAVE COMMUNICATION PRODUCTS

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February 11, 1998

Ms. Magalie Roman Salas
Secretary
Federal Communications Commission
2000 M. Street, N.W. - Suite 480
Washington, DC 20554

EX PARTE OR LATE FILED

Re: EX PARTE
ET Docket 95-18
RM - 7927
PP - 28

Dear Ms. Roman Salas,

As President of Nucomm, Inc., a microwave equipment manufacturer, I want to bring to your attention the results of recent laboratory and field tests conducted by Nucomm to examine the use of digital microwave technology for the broadcast industry. The study, a copy of which is attached, reviews how the digital video microwave technology can be applied to fixed point-to-point and electronic news gathering ("ENG") systems and consider the trade-offs of digital vs. analog video microwave systems.[1] We wish to submit our study to be included as part of the record in the above noted proceeding.

Recent FCC rulings on HDTV changed the microwave link requirements regarding digital video microwave for broadcast applications. The broadcast industry is increasingly interested in digital video technology as a means of enhancing existing systems and demand for digital video microwave will require the microwave manufacturer to supply new equipment components. Although a wide array of digital products such as digital cameras, editors, storage devices and encoders is available, little has been said about converting the fixed point-to-point studio-to-transmitter link ("STL"), transmitter-to-studio link ("TSL"), intercity relay ("ICR"), and ENG microwave link from analog to digital transmission, a critical part of the total production system.

Nucomm has conducted both laboratory and field test using digital video microwave systems in fixed point-to-point and ENG applications in order to inform TV station engineers about the advantages, disadvantages and trade-offs of digital vs. analog video microwave systems. These test results show that applying digital video to STL and ENG microwave systems can conserve frequency spectrum and yield superior quality and performance equal to or better than analog systems under both fading and multi-path environments.

[1] The study is also available to the public on the internet on our homepage (www.nucomm.com) in the directory Apps Notes..

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We have presented the results of our test at several industry conferences including: the Society of Broadcast Engineers ("SBE") September 26, 1997 meeting/conference in Syracuse, New York; the October 22-24, 1997 SBE conference in Seattle, Washington; and the Society of Motion Picture and Television Engineers ("SMPTE") conference in New York City on November 21-24, 1997.

We also would be happy to present our finding to you if you would find them of interest. Please feel free to call to set up an appointment if you are interested in further details regarding the study.

Sincerely,

John Payne

Dr. John B. Payne, President
Nucomm, Inc.

cc: Secretary Salas
Enclosure

NuComm

Microwave Communications Products

TOMORROW'S TECHNOLOGY TODAY

Digital Video Microwave Systems for STL and ENG Applications & Test Results

By Dr. John B. Payne, President
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NAB97, the FCC ruling on deadlines for HDTV and recent acts by Congress have signaled the dawn of a new era for Digital Video Microwave for broadcast applications including Fixed Point-to-Point (i.e. STL, TSL, ICRS etc.) and ENG in the United States and the world. The manufacturers of the digital CODEC, Multiplexer (MUX) and MODEM equipment have little if any knowledge of the microwave link requirements. Further more they appear to have no interest in integrating these systems. Therefore, the demand of Digital Video Microwave Fixed Point-to-Point and ENG will require the microwave manufacturer to supply part or all of a turnkey package including the transmitting/receiving equipment, CODEC, Multiplexer and MODEM components. This offers an excellent opportunity as well as a challenge for the manufacturers of Digital Microwave equipment to move into a new and expanding market area.

Because of this, it has become increasingly important for TV Station Engineers to know the advantages, disadvantages and tradeoffs of Digital vs. Analog Video Microwave Systems. The purpose of this paper is to:

- Present an overview of how the Digital Video Microwave technology will be applied to STL and ENG systems,
- Present actual laboratory and field results of tests conducted by NUCOMM using Digital Video Microwave Systems in STL and ENG applications.

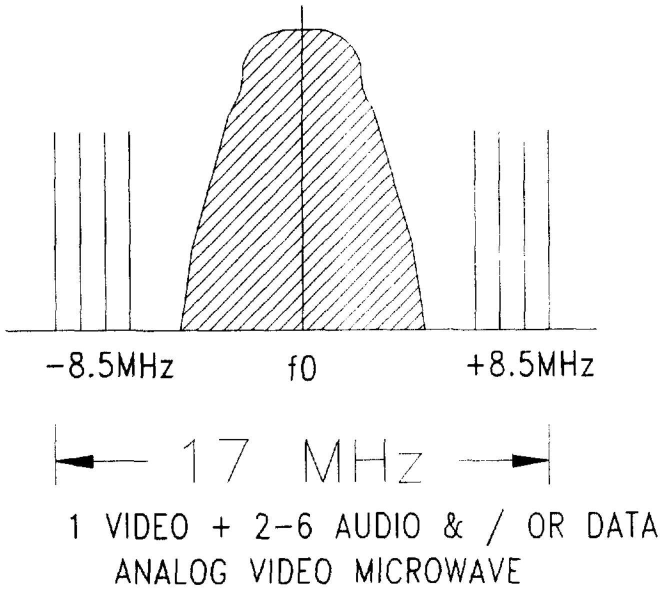
Conclusions: Applying digital video to microwave systems for STL and ENG systems can conserve frequency spectrum and yield superior video and audio quality and performance equal to and better than analog systems under both fading and multi-path environments.

A - Why Digital ?

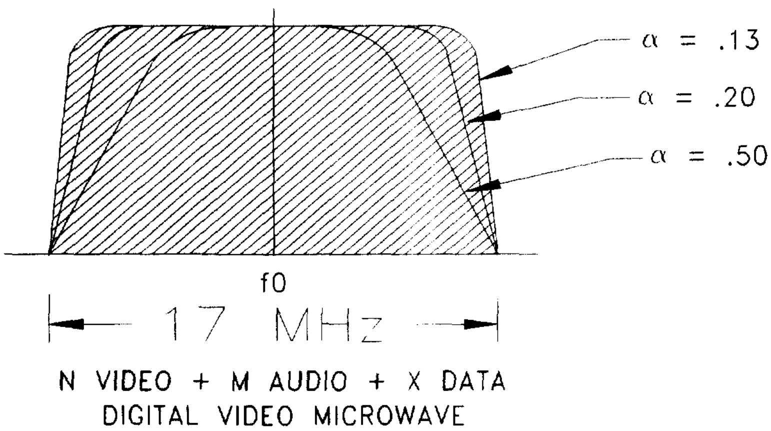
The basic answer to "WHY DIGITAL" is that transmitting in a digital format makes much more efficient use of allocated frequency spectrum. However, another advantage is that of an error-free picture under most conditions. **Frequency spectrum is like land here on earth! No more is being made.** Therefore, we must learn to make the best of what we have. And, what we have is in high demand.

To demonstrate how digital video microwaves can make better use of the allocated bandwidth, refer to the example in Figure 1 below. This shows the spectrum of an analog signal and that of a digital signal. The analog spectrum is for a single video and four audio FM transmitter. Its spectrum falls within a 17 MHz bandwidth such as in the 2 GHz band. All of the empty space within this band that is not occupied by the analog signal can be considered wasted spectrum.

The lower spectrum in Figure 1 is that of a transmitter being phase and amplitude modulated with a digital bit stream. It can be seen that the spectrum is better utilized. Ideally the desired shape would be a perfect rectangle. The closer the spectrum approaches the rectangular shape, the more information can be transmitted in a given bandwidth. It is the RF Digital Modulator that receives the data pulses and converts them to a 70 MHz modulated signal. The Digital Modulator and Demodulator when combined in a single unit are referred to as a MODEM. In



Spectrum of Analog Modulation
(A)



Spectrum of Digital Modulation
(B)

Spectrum of Analog and Digital Modulation
Figure 1

this paper and for terrestrial microwave we refer to them separately as Digital Modulators and Digital Demodulators since they are generally packaged separately and usually as part of the transmitter and receiver units.

To obtain the desired spectrum shape of Figure 1B, the data pulses that are inputted to the Modulator must be shaped by a low-pass-filter, referred to as a Finite Impulse Filter (FIR), to produce the desired spectrum shape. The parameter that relates the pulse shape to the spectrum shape (which is a function of occupied bandwidth) is the α parameter. The spectrum is shown for three different pulse shaping networks. When $\alpha = .13$ the spectrum is seen to be extremely efficient. Practical values for α range $.13 < \alpha < .50$ with .20 being a typical value.

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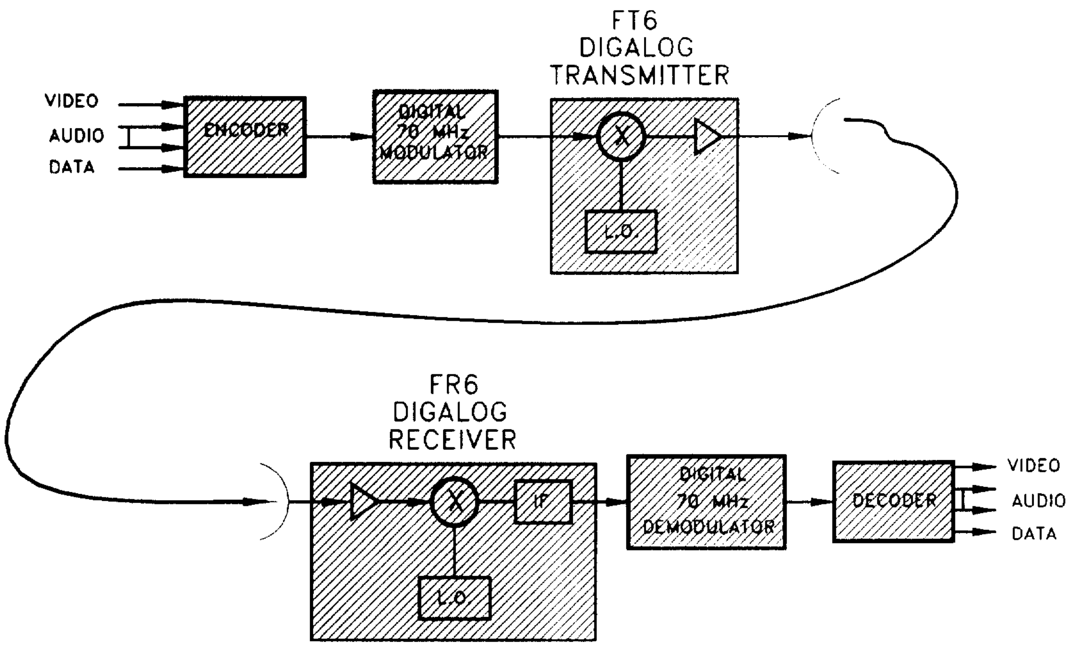
B - Digital Video Microwave Architecture:

The modulation and type of microwave radio required to transmit Digital Video information is considerably different from that used for Analog Video transmission. Figure 2 shows a simplified block diagrams of a Digital microwave system for transmission of a single video picture. The modulation process is considerably different from Analog modulation. Here the Video and Audio input signals are first digitized, then compressed and finally combined with the digital Data inputs. The unit that does this digitizing , compressing and combining is referred to as an Encoder. Generally the Encoder adds some Forward Error Correction (FEC). The output from the Encoder is a digital bit stream in either serial or parallel form. The output is generally measured in terms megabits per sec (Mbits/s). The output data rate from the Encoder depends on the amount of compression used and FEC. Typically the output data rate would be in the range of 1.5 to 34 Mbits/s (some applications require rates as high as 45 Mbits/s).



Single Digital Video Heterodyne System
Figure 2

If a single video, audio data combination is to be transmitted as shown in Figure 2, the Encoder output is directly converted to a 70 MHz RF signal in the Digital Modulator. The modulation used in Digital Modulators typically is QPSK or multiple level PSK or QAM. This type of modulation is considerable more complicated than the FM modulation used in analog radios. Both QPSK and QAM use a combination of phase and amplitude to modulate the 70 MHz carrier.

The 70 MHz QPSK or QAM Digital Modulator output is up-converted (heterodyned) to the RF microwave frequency and amplified in a linear type RF amplifier. The RF microwave signal is sent directly to the antenna or diplexer with other microwave signals.

At the receive end the RF signal is down-converted to 70 MHz and the Digital Demodulator outputs the compressed data stream. The digital data stream is then decoded (uncompressed) in the Decoder to produce the final video, audios and data.

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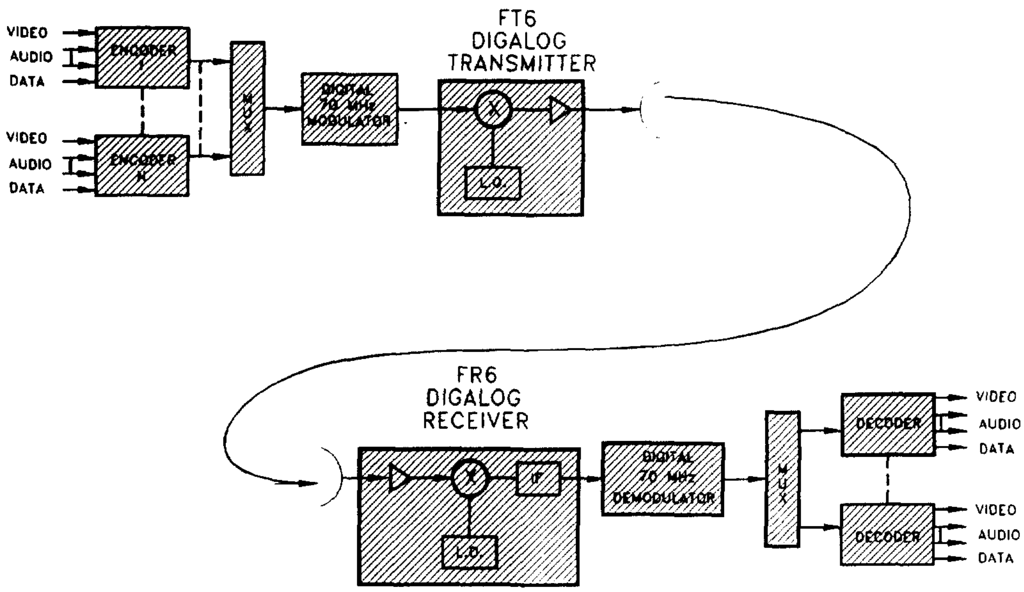
At the receive end, the Digital Demodulator and Decoder components are general combined in a single receiver with the input at 70 MHz or L-band (IRD).

However, depending on the manufacture, the type of compression used (MPEG-2, ETSI or other proprietary compression) and the Encoder output data rate, the demodulator and decoder may require specially designed boxes.

Figure 3 shows a block diagram for combining multiple video, audio and data onto a single microwave carrier. Multiple encoders are used to digitize, compress and combine the inputs from each source. The multiple encoder outputs are combined by a Multiplexer that outputs a digital stream at a rate equal to the sum of the input data streams. That is, if two Encoders output 15 Mbits/s and 10 Mbits/s respectively, then the multiplexer output will be at about 25 Mbits/s.

The multiplexer output data stream is feed to the Digital Modulator that in turn converts the data from the Multiplexer to a QPSK or QAM phase and amplitude modulated 70 MHz signal. The microwave heterodyne transmitter up-converts the 70 MHz to the desired operating frequency.

Typically, the digital components on the transmitter end take on the form shown in Figure 3. However, some manufactures integrate the Encoder, Multiplexer and 70 MHz Modulator into a single piece of equipment.



Multiple Digital Video Heterodyne System
Figure 3

At the receiver end the microwave signal is down-converted and demodulated. The multiple encoded data is divided into multiple channels by the Demultiplexer before being decoded in individual Decoders. Often but not always, the demodulator, demultiplexer and decoding are done in a single, less expensive Integrated Receiver Decoder (IRD).

It must be remembered that digital encoding and decoding technology is still evolving with standards still being modified or just being proposed. Today's prices will come down considerably over time as standards are established and competition increases. Today there are at least 10 manufacturers of digital encoders and decoders. There are many more that are just starting development. Competition will be very strong in the coming years.

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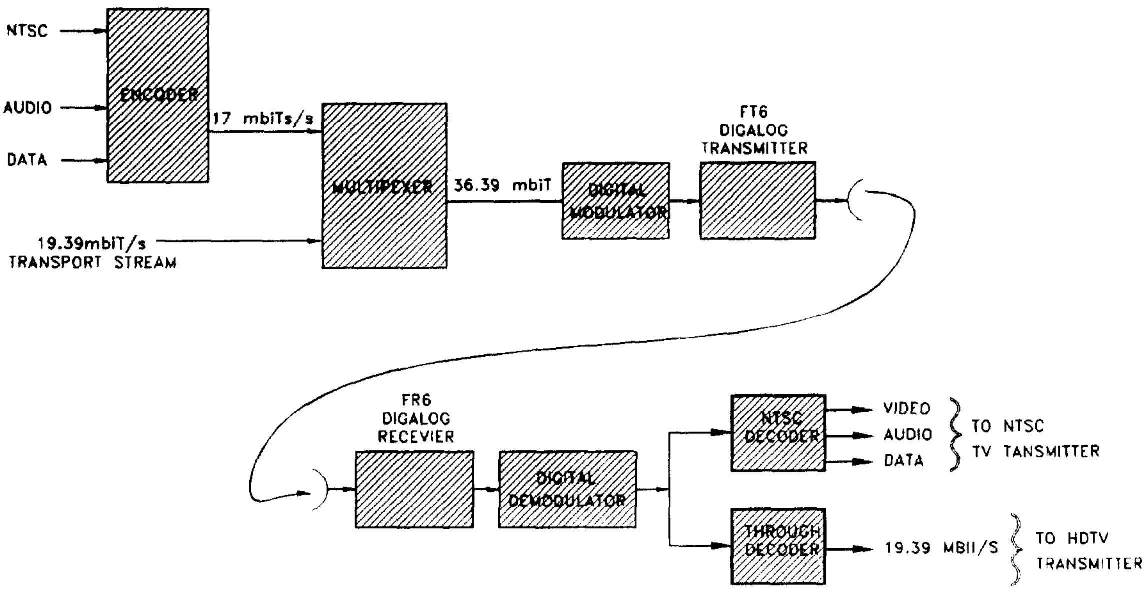
C - NTSC and HDTV Dual Channel STL:

Figure 4 shows how the NTSC and the HDTV transport stream can be simultaneously transmitted from the studio to the transmitter, over a single microwave link. The NTSC (or PAL-B/G) composite signal is digitized and compressed to the desired output rate, ie, 15-25 Mbits/s. This is combined with the 19.39 Mbits/s (or 45 Mbits/s) HDTV transport stream to yield an input Data rate to the Digital Modulator of 34.4 for the 15 Mbit/s encoder output (44.4 Mbits/s for 25 Mbits/s encoder output). Using a QPSK Modulator the bandwidth required to transmit the 34.4 Mbits/s is about 22 MHz. Using 16QAM the bandwidth is reduced to 11 MHz. and 30 MHz, which would be adequate for 7 or 13 GHz. For higher NTSC data rates or operation a 2 GHz, 8PSK or 16 QAM would be required.



Dual Channel Digital Video STL for NTSC and HDTV
Figure 4

On the receiver end, the received signal is demodulators and applied to two Decoders. The NTSC Decoder outputs the composite and audio signal to be applied to the NTSC transmitter. The other Decoder acts as Demultiplexer and passes the HDTV transport stream through to the HDTV transmitter. **NUCOMM offers a complete turnkey system for this application.**

D - DIGALOG - Digital & Analog Microwave System:

To meet the broadcasters immediate need for continued transmission of analog signals today but to be ready for the coming transition to digital, NUCOMM has developed the DIGALOG FT6/FR6 Radio system. The DIGALOG Radio operates as an analog radio today but is configured for digital operation tomorrow. Figure 5 shows a block diagram of the DIGALOG FT6 transmitter that can operate in both Analog and Digital modes. The Analog Modulator is supplied for analog operation. The Digital/Analog power amplifier is operated in its Analog mode for maximum power output. When the user is ready to go digital, the Digital Modulator can be added to the same two rack high unit. A single switch on the inside of the front panel switches the power amplifier to its Digital mode.

Figure 6 shows a block diagram of the DIGALOG FR6 Analog/Digital microwave receiver. The receiver is supplied with an analog demodulator for analog operation. A digital demodulator can be installed at a later time. Two IF bandwidths, 30 and 45 MHz, are provided in the IF amplifier. The 30 MHz bandwidth filter is to be used for analog or low data rate digital operation. For data rates of 45 Mbits/s or higher, the 45 MHz bandwidth filter is switched in.

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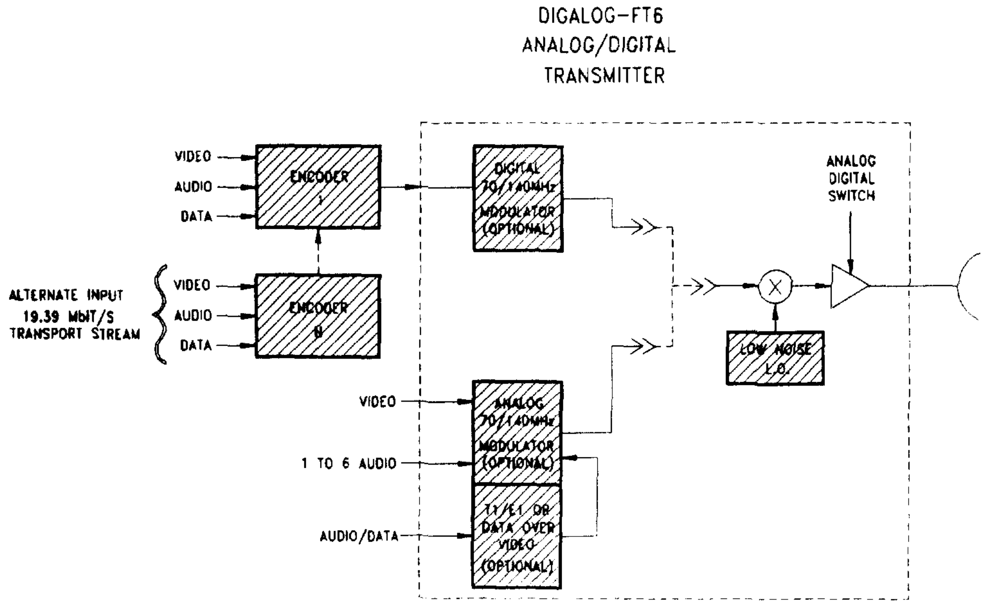
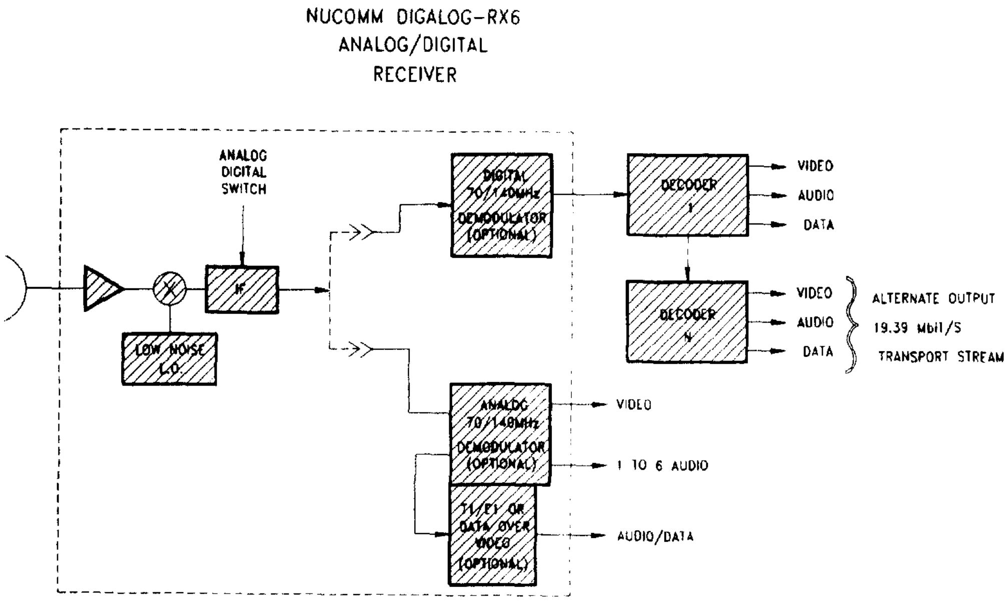


DIGALOG FT6
Analog/Digital Microwave Transmitter
Figure 5



DIGALOG FR6
Analog/Digital Microwave Receiver
Figure 6

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E - DATA RATE verses BANDWIDTH of a Digital Video Microwave System:

Equation 1.1 below defines the Bandwidth required to transmit a bit stream of a given data rate. The shape of the transmitted spectrum will like that shown in Figure 1B. The transmitted bandwidth is a function of input Data Rate (Za), Modulation Coding (M) for such methods as QPSK, 8PSK and 16QAM, Forward Error Correction and the Spectrum Shape Factor (α).

$$\text{Bandwidth} = \frac{(1+\alpha)\sum Z_a \text{ Mbits/sec}}{FEC * M} \qquad (1.1)$$

where $\sum Z_a$ = Sum of Data Rates from one or multiple Encoders in Mbits/sec.

FEC = VC * RS

FEC = Forward error correction ; If no FEC is used, then FEC=1

VC = Viterbi Coding: Typical 1/2, 2/3, 5/6, 3/4, 7/8and

RS = Reed-Solomon: Typical 188/204, 192/208.

M = 2, 3, 4, 5, 6, 7, 8 :Coding level of the Modulator ; see TABLE 1.

α = Spectral Shaping Factor.

Table 1 gives the values for M, the Modulation Coding, for common forms of modulation used in digital systems. Also given is the bit efficiency, in Bits/Hz/s, for each form of modulation for a typical $\alpha = 0.2$. Note that as M increases, the required bandwidth to transmit a given data rate decreases by the Bits/Hz/s number (assuming FEC=1). Also, as the Modulation Coding number M increases, the required received carrier-to-noise (C/N) level must increase for a given Bit Error Rate. This is the price we must pay for better transmission efficiency. The C/N for each M is given for a normalized C/N power ratio corresponding to a BER of $1X10^{-6}$.

Table 1
Types of Modulation

TYPE OF MOD.	M	Bits/Hz/s $\frac{M}{(1+\alpha)}$	C/N (dB)
PSK	1	.833	10
QPSK	2	1.66	10
8PSK	3	2.50	14
16QAM	4	3.33	17
64QAM	6	5.00	23
256QAM	8	6.66	28

Notes: 1-Normalized carrier-to-noise power ratio corresponds to a BER of $1X10^{-6}$.
2-Assumes No Error Correction
3-Assumes $\alpha = .20$

The most robust and common form of digital modulation is QPSK. From Table 1, it can be seen that this will result in a bandwidth reduction of 1.66. In many cases more bandwidth reduction may be required such as 3.33 for 16QAM or 5.0 for 64QAM. As the coding number increases, the signal will become much more susceptible to RF interference, multi-path effects, etc. Also the system gain decreases substantially due to lower available output power and the requirement for higher receive carrier levels for a given bit error rate.

In an STL link where strong signal levels are the norm but picture quality and link reliability are important, the higher forms of modulation can usually be justified. However, in ENG links where multi-path and weak signals are the norm QPSK would be the recommended form of modulation. Generally in ENG operations, getting the picture through is of higher priority than picture quality, therefore QPSK is recommended. To fit the Digital Video data rate within the allocated bandwidth, the Encoder data rate only needs to be reduced and the FEC adjusted to obtain a reliable picture. Reducing the data rate with today's Encoders has little effect on the picture quality as will be shown from the test results given at the end

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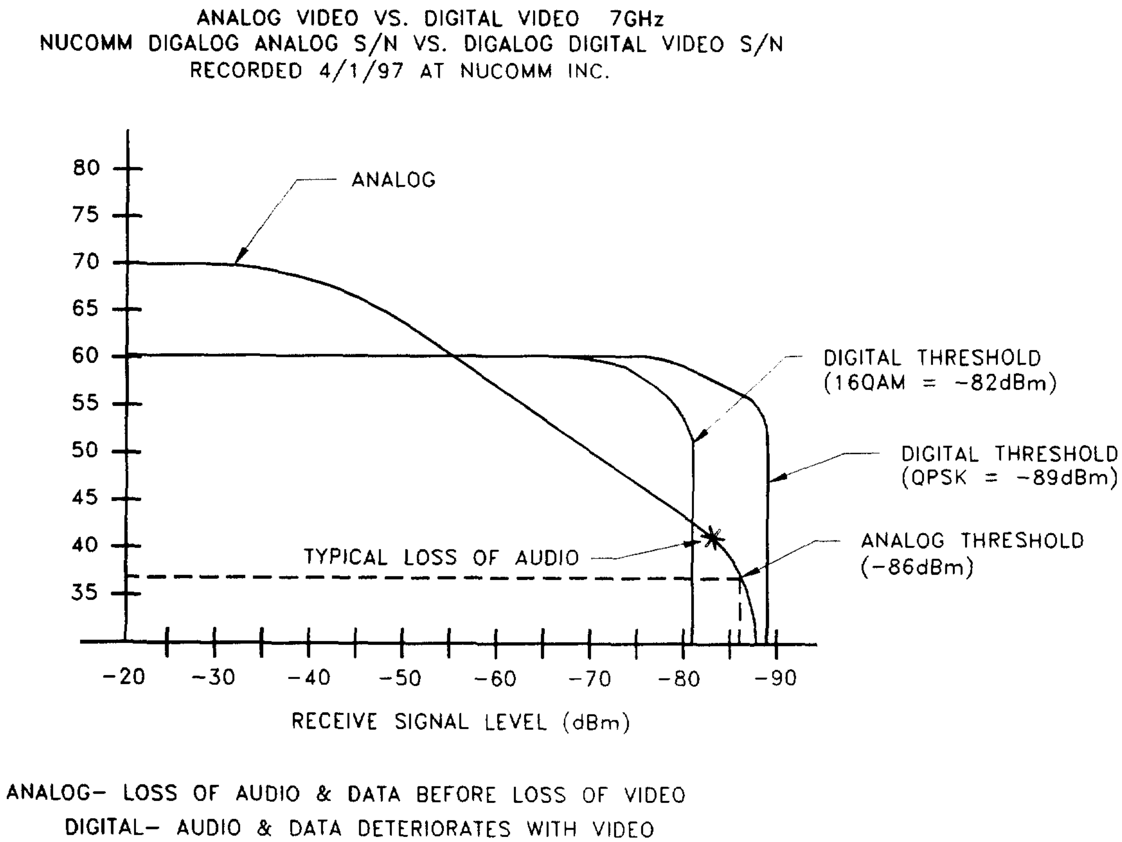
of this paper. Therefore, it becomes a judgment call on the part of the ENG management whether to give up some picture quality for a reduced bandwidth. There may be no other option as the 2 GHz allocated bandwidths are further reduced by the FCC.

F - Typical Analog vs. Digital Performance:

Figure 7 shows the performance of an Analog link and a comparable Digital link (as shown in Figure 2, 3 or 4). The Analog link shows a video S/N of 70 dB for high receiver input signal levels. As the signal level drops, the video S/N will begin to drop in a linear relationship to the input signal level. When the receiver threshold is reached (typically -85 dBm at 7 GHz in today's video receivers), the video S/N drops much more rapidly than the receiver input signal level. In a typical analog system, threshold is defined when the video S/N reaches -37 dB. At a receive level of about -82 dBm the audio channels will become very noisy and unusable.



Video S/N Verses Receiver Signal Level
for Analog & Digital Systems
Figure 7

The Digital link shows a lower video S/N than the Analog link for strong receive signal levels. This lower S/N is due to quantizing errors in the digitizing of the video signal in the Encoder. Typically, a 10 bit digitizer will give a video S/N of about 60 dB. The advantage of the digital system is seen as the input signal level is reduced, the video S/N remains constant at 60 dB. This S/N will be maintained until the error correcting can no longer handle the error. The system then crashes. The result is that the video picture freezes. The point at which the S/N "fall off the cliff" is generally at or below the analog

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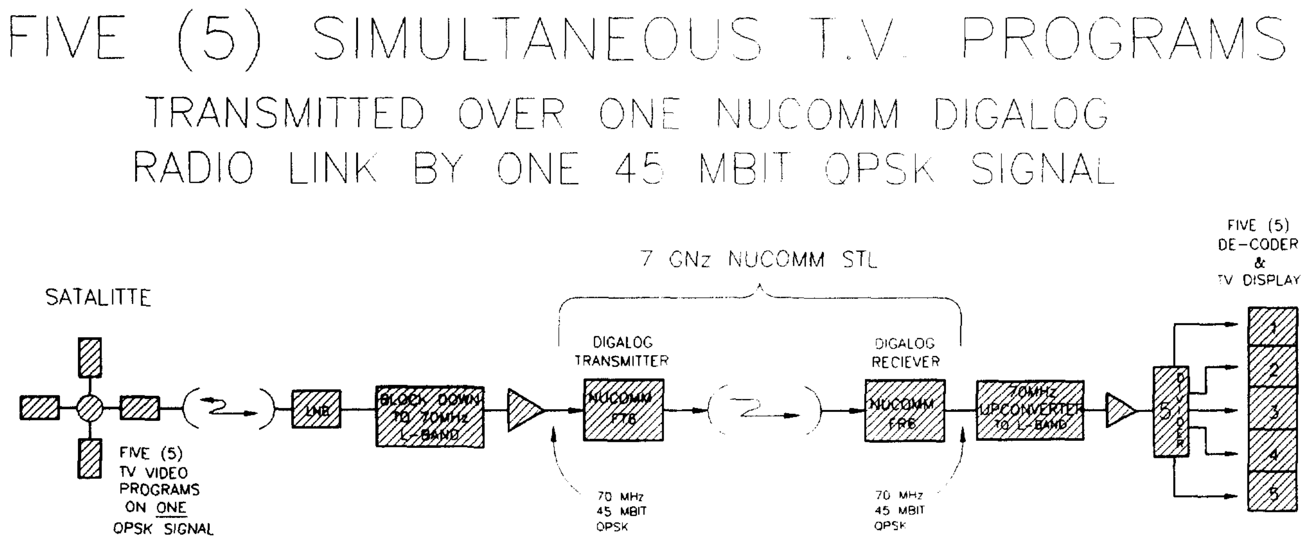
threshold point. This "fall off the cliff" point depends primarily on the amount of error correction that is built into the Encoder and/or the Modulator and the type of modulation used.

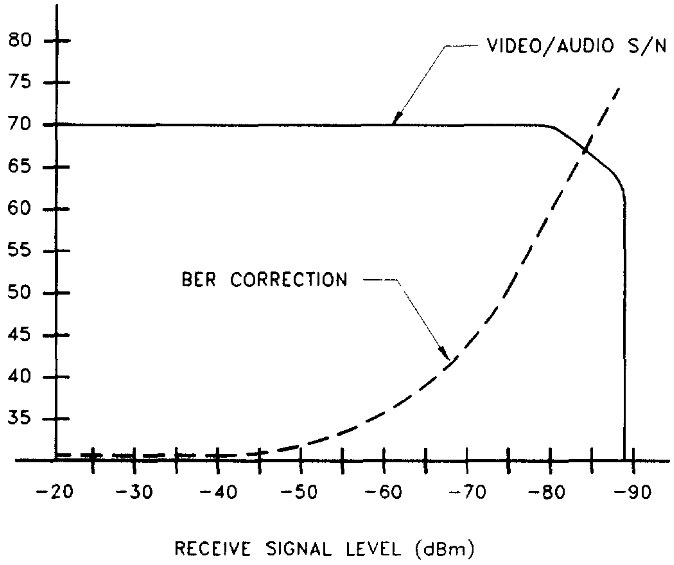
NUCOMM passed a 45 Mbit-QPSK digital signal with error correction through the NUCOMM 7 GHz FT6/FR6 DIGALOG (Analog/Digital) transmitter and receiver, the cliff point was 4 dB below (-89 dBm) the system's analog threshold. An additional advantage is that the audio and data channels remain at a high S/N level until the cliff point is reached. Using 16QAM, the digital threshold is worse than the analog threshold by 3dB. This 7dB reduction in threshold by using 16QAM instead of QPSK (as shown in TABLE 1) has enabled us to transmit twice the data rate within the same bandwidth.

G - STL/Line of Sight Experimental Results:

NUCOMM tested a Digital Video Microwave System setup as shown in Figure 8. A 45Mbit QPSK signal carrying five video programs plus one audio per video was down-linked from a USSB satellite. This signal was first down-converted to 70 MHz. The 70 MHz signal was inputted to a NUCOMM 7 GHz DIGALOG radio operating in the Digital mode. The output of the transmitter was attenuated through a variable attenuater so as to reduce the signal level at the receiver input to well below the receiver threshold. The receiver's 70 MHz output was upconverted to L-band and fed to five satellite receivers. The output of each satellite receiver was displayed on a color monitor. The satellite receivers have a built in bit error rate counter that displays the BER as signal strength. A signal strength reading of 100 means that there are no errors being detected. A reading of 10 means that there are many errors. Below this level the system crashes. Figure 9 below shows the result measured using a VM700 to measure the video signal-to-noise and the built-in signal strength BER indicator to show how the bit errors change with the microwave receiver signal strength. The Analog threshold of the system in the Analog mode was measured at -85 dBm. Note that the Digital threshold or "Cliff" point is at -89 dBm. That is 4 dB better than in the Analog mode. Just as important is the fact that all five video pictures and audio sound remained perfect until the "Cliff" point was reached. The difference in signal level between a perfect picture and a frozen picture was 1 dB.



Test Setup for Measuring Digital Video Performance
Figure 8



Test Results from Experimental Test Setup
Figure 9

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H - Digital ENG 2 GHz Field Test with Extensive Multi-Path:

When the subject of Digital Video being applied to 2 GHz ENG microwave systems is suggested, the immediate response by many ENG operators is that Digital Video will never work for ENG because they are typically faced with non-engineered paths in which many shots are made using multiple bounces in high multi-path environments and these conditions will cause the picture to freeze thus losing the shot, and some picture is better than no picture. Furthermore, it has been suggested that moderately long STL paths will be severely effected by multi-path and selective fading.

To start to answer some of these questions, NUCOMM has recently completed testing of its 2 GHz ENG Digital Video microwave system in New York City. New York city was chosen because it represents one of the most severe and challenging environments for ENG operation. The results as given in this section were startingly successful to all who participated. The principle objectives of the field tests were:

Digital ENG Field Test

- Test reliability and feasibility of digital MPEG-2 compression and QPSK modulation to digitally transmit an ENG microwave signal under various multi-path conditions.
-
- Compare the audio video quality of the digital signal with a typical analog FM signal
-
- Assess how much forward error correction is required to ensure robustness of digital signal transmission in multi-path environments.

I want to acknowledge and thank New York City FOX station WNYW-TV and in particular Rich Paleski for providing the ENG truck, their Empire State Building Central Receive site as well as studio recording equipment and personnel. Rich is a seasoned New York ENG engineer well acquainted with the many difficult multi-bounce and multi-path ENG shots in that city. I would also like to recognize and thank the WEGENER corporation who supplied the Encoding and IRD equipment.

The equipment configuration for this test is shown in Figure 10. The Analog transmitter was a NURAD 10 Watt model PT1. Its output was padded down for an output of 3 Watts. The Digital transmitter was a NUCOMM DIGALOG FT6. Its power output was 1.5 Watts. The power amplifier on the mast at the antenna could not be used because it was operated in saturation and caused excessive spectrum spreading. The antenna was connected directly to the transmitters through 50 feet of Andrew ½ inch flexible coax and had a measured loss of 3 dB. The antenna was a NURAD silhouetta antenna mounted on a pan and tilt. To ensure stress testing the digital encoder, a difficult 2.5 minute video clip of a pre-recorded hockey game on Betacam-SP was used as source material that included fast camera panning, fast action, high color contrast, and saturated colors.

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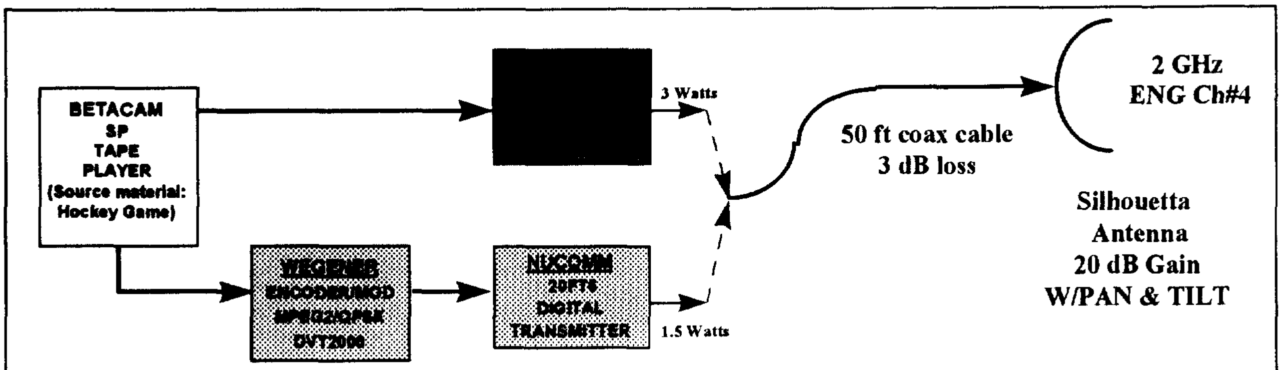
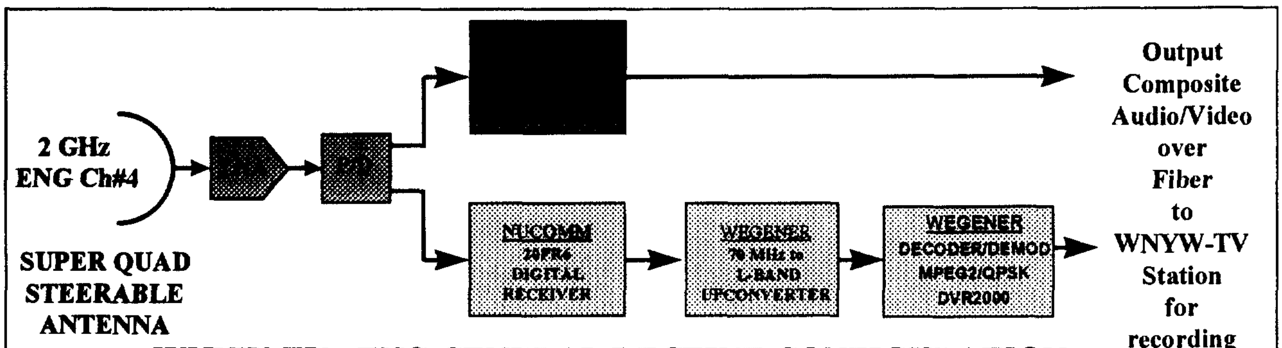
System Components and Parameters

- Analog Transmission
  - Nurad 20PT1 Transmitter, operating at ~3 Watts
  - 17 MHz bandwidth
- Digital Transmission
  - Wegener DVT 2000 MPEG-2 Digital Encoder and QPSK Modulator
  - Nucomm 20FT6 Digital Transmitter, operating at ~1.5 Watts
  - Tested encoding rates from 9 to 15 Mbps
  - Tested forward error correction rates of 1/2, 2/3, 3/4, and 7/8
- 3 Transmission Paths
  - Case 1: Direct Line-of-Sight Transmission
  - Case 2: Moderate multi-path (One Bounce + Reflections)
  - Case 3: Extreme multi-path (Multiple Bounces + Reflections)



WNYW-TV - ENG VAN-TRANSMITTER CONFIGURATION



WNYW-TV - ENG CENTRAL RECEIVE CONFIGURATION at the EMPIRE STATE BUILDING

Figure 10

At the Empire State Building the output from a steerable Superquad antenna was divided and fed both the NURAD analog receiver and the NUCOMM DIGALOG FR6 digital receiver simultaneously. The 70 MHz output from the digital receiver

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was upconverted to L Band to feed the IRD decoder. Each of the composite outputs from both the analog and digital receive systems was transmitted back to the studio over an analog fiber link where the outputs were recorded to Betacam SP tape. Both transmitters were operated on the same 2 GHz channel. Operating on two different frequencies could have negated the tests since multi-path effects would be different.

The first three case tests compared the audio and video quality of the 2 GHz analog FM signal with the quality of the digital MPEG-2 compressed and QPSK modulated signal under the following three environments: (1) direct line-of-sight transmission, (2) moderate multi-path transmission, and (3) extreme multi-path transmission. In each case, the ENG truck was located at E. 90th St. and 5th Ave. and the receive site was the Empire State Building located at E. 33-34th St. and 5th Ave. The antennas on both the transmit and receive sites were steered accordingly to establish the appropriate transmission environment. Figures 11, 12 and 13 show the direction of the ENG shots for each of the three cases respectively. The procedure for setting up each test was to first establish the analog shot geometry and picture quality. The resultant analog video picture was recorded for 2.5 minutes. Then, without moving the antennas, the digital transmitter was connected and the test repeated. Each digital test was conducted using the data rates and FEC shown in the accompanying table.

Digital ENG Test Site

ENG Transmit Truck: E. 90th & 5th Ave.

Empire Receive Site: E. 33-34th & 5th Ave.

WNYW-TV Station: E. 67th & 2nd-3rd Ave.

Test Case 1:

The first test was a line-of-sight shot, as shown in Figure 11, to make sure that the system was working properly. Both analog and digital transmissions overall produced good pictures for each configuration as shown in the table and accompanying the split screen pictures. Although the analog signal is strong, the upper analog portion shows that there were still some multi-path and ghosting artifacts, where the lower digital portion of the picture shows no sign of multi-path or ghosting.

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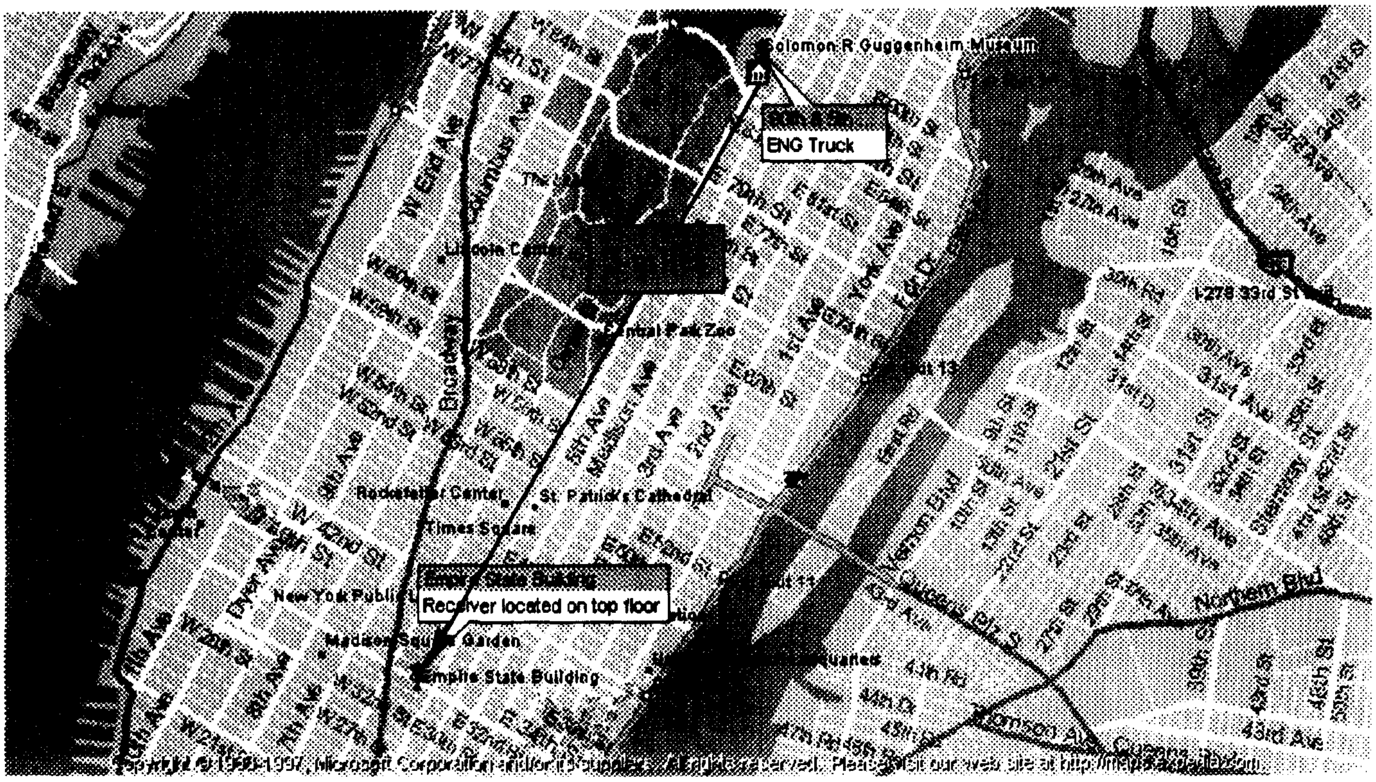
Case 1: Direct Line-of-Sight Transmission



Strong Analog Signal
Very Good Digital Picture

Figure 11

Test Results for Case 1: Direct Line-of-Sight

Mode	Bit Rate	FEC	BW	Rcv. Signal Level
Analog FM			17 MHz	-25 dBm
Digital	9 Mbps	3/4	8.5 MHz	-28 dBm
	10.5 Mbps	7/8	8.5 MHz	-29 dBm
	12.5 Mbps	3/4	12 MHz	-28 dBm
	15 Mbps	7/8	12 MHz	-28 dBm

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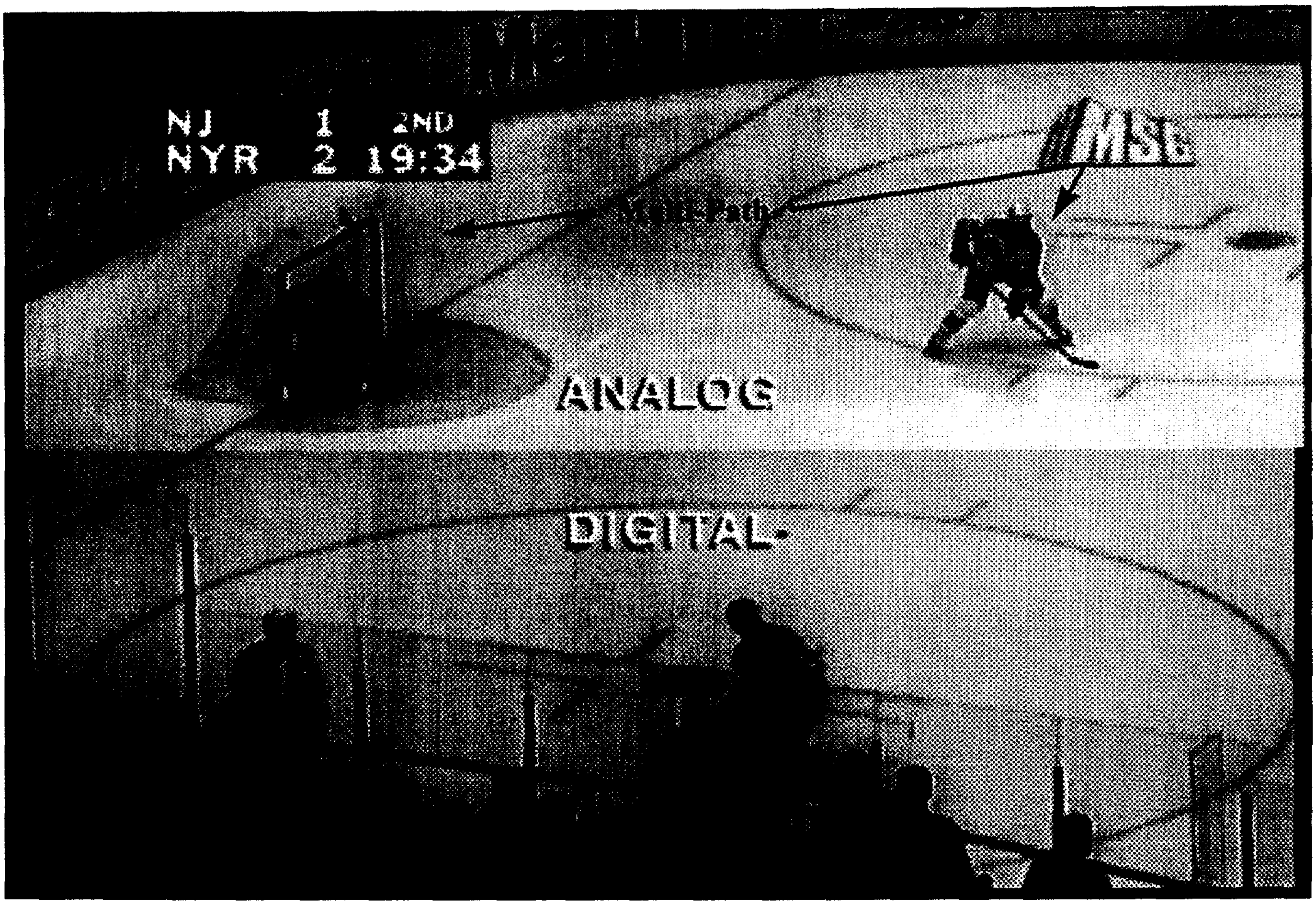
Picture Quality of Analog vs. Digital (9 Mbps, 3/4 FEC) Transmission for Case 1: Direct Line-of-Sight



Test Case 2:

The second case, moderate multi-path transmission, is representative of typical ENG operating conditions in major urban cities, such as New York City where buildings are commonplace obstructions to obtaining direct line-of-sight transmission. The ENG truck was still in the same location as in the first case, but the antenna was moved to 45 degrees off of true North so that at least one bounce was introduced in the path. Figure 12 shows the second test geometry of the signal bouncing off a building located approximately behind the ENG truck. The received signal measure was lower than the first case but still quite strong. The resulting analog signal showed noticeable ghosting artifacts and color shifting. The quality of this analog signal was considered a borderline usable picture for broadcasting. The digital signal, on the other hand, had no problem locking up and performed perfectly with no ghost or indication of multi-path in the picture for all test configurations as indicated in Case 2 split screen picture and table.

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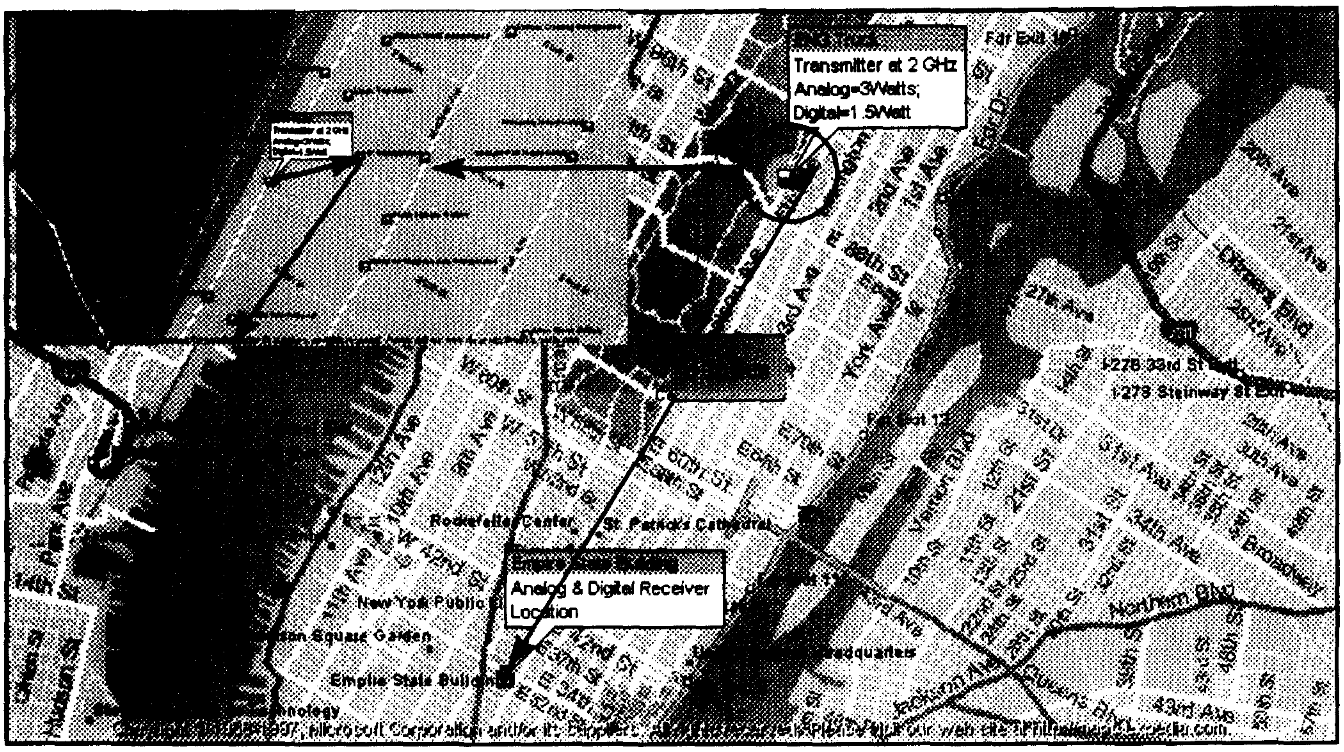
Case 2: Moderate multi-path (~180 degree Bounce Shot)



Borderline Quality / Moderate Analog Signal
Very Good Digital Picture

Figure 12

Test Results for Case 2: Moderate multi-path

Mode	Bit Rate	FEC	BW	Rcv. Signal Level
Analog FM			17 MHz	-56 dBm
Digital	9 Mbps	3/4	8.5 MHz	-60 dBm
	10.5 Mbps	7/8	8.5 MHz	-60 dBm
	12.5 Mbps	3/4	12 MHz	-60 dBm
	15 Mbps	7/8	12 MHz	-60 dBm

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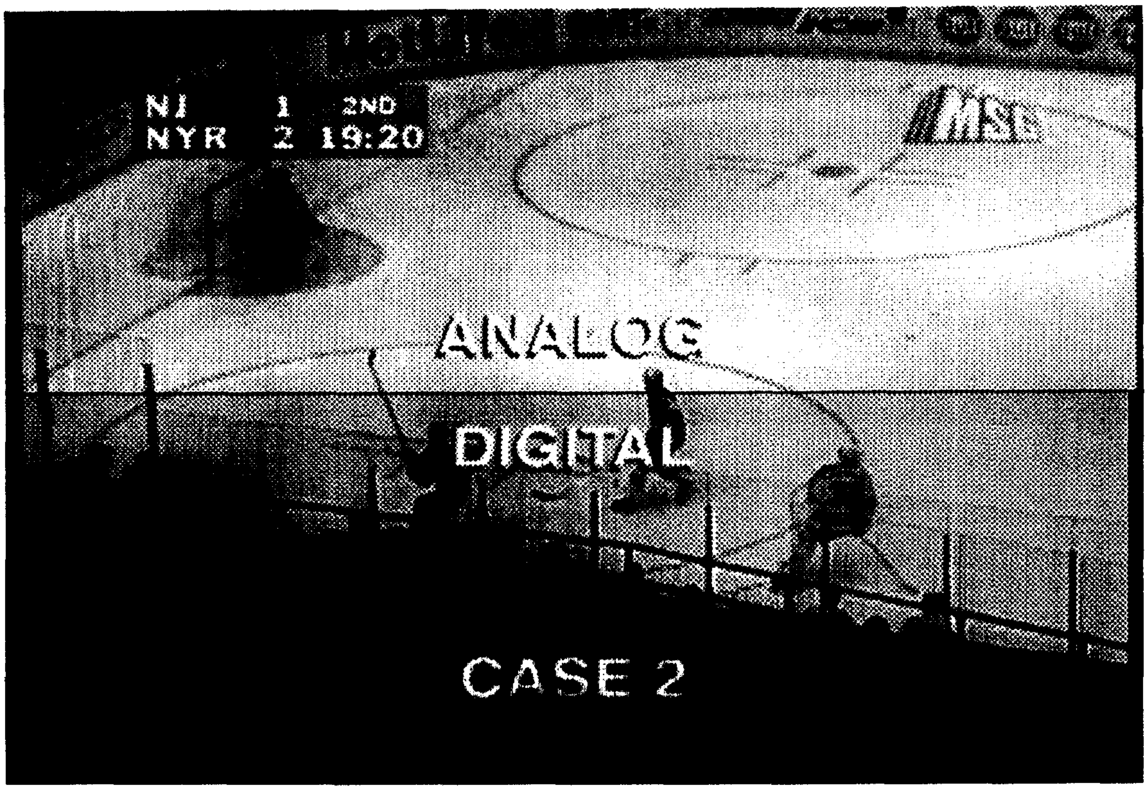
Picture Quality of Analog vs. Digital (9 Mbps, 3/4 FEC) Transmission for Case 2: Moderate multi-path



Test Case 3:

The third case tested extreme multi-path interference comprising of multiple reflections and scattering from buildings and possibly even moving vehicles. Here the ENG truck antenna aimed in the general direction toward the west side of Central Park as shown in Figure 13. The resulting transmitted analog signal was severely degraded to the point where it was not at all usable and was so bad that a frame synchronizer had to be used to receive the picture. The analog video had significant ghosting artifacts and the audio had severe breakup. The studio reported that the picture quality was too poor to broadcast. With the digital signal using an FEC of 3/4, the IRD Decoder had no problem locking on the signal and produced a perfect picture.

The hockey picture shown below is a split image of the same video picture transmitted in both analog and digital modes. The analog signal, shown in the upper half, contains very noticeable ghosting artifacts and color distortions. The digital signal, on the other hand, located in the lower half, is a clean, well-defined picture with no multi-path or noise.

In the presence of extreme multi-path, a 7/8 FEC was clearly not enough and the resulting errors can be observed by occasional slow picture motion, checker-boarding and dropouts. As predicted, an FEC rate of at least ¾ was required to adequately recover from random errors induced by multi-path interference, and in our tests, an FEC rate of ¾ seemed sufficient to recover from most errors. This test shows how important forward error correction is and that the signal path was fully testing the capabilities of the digital signal capability to operate in the multi-path environment. The following table shows test results for other data rates and FEC done on this shot.

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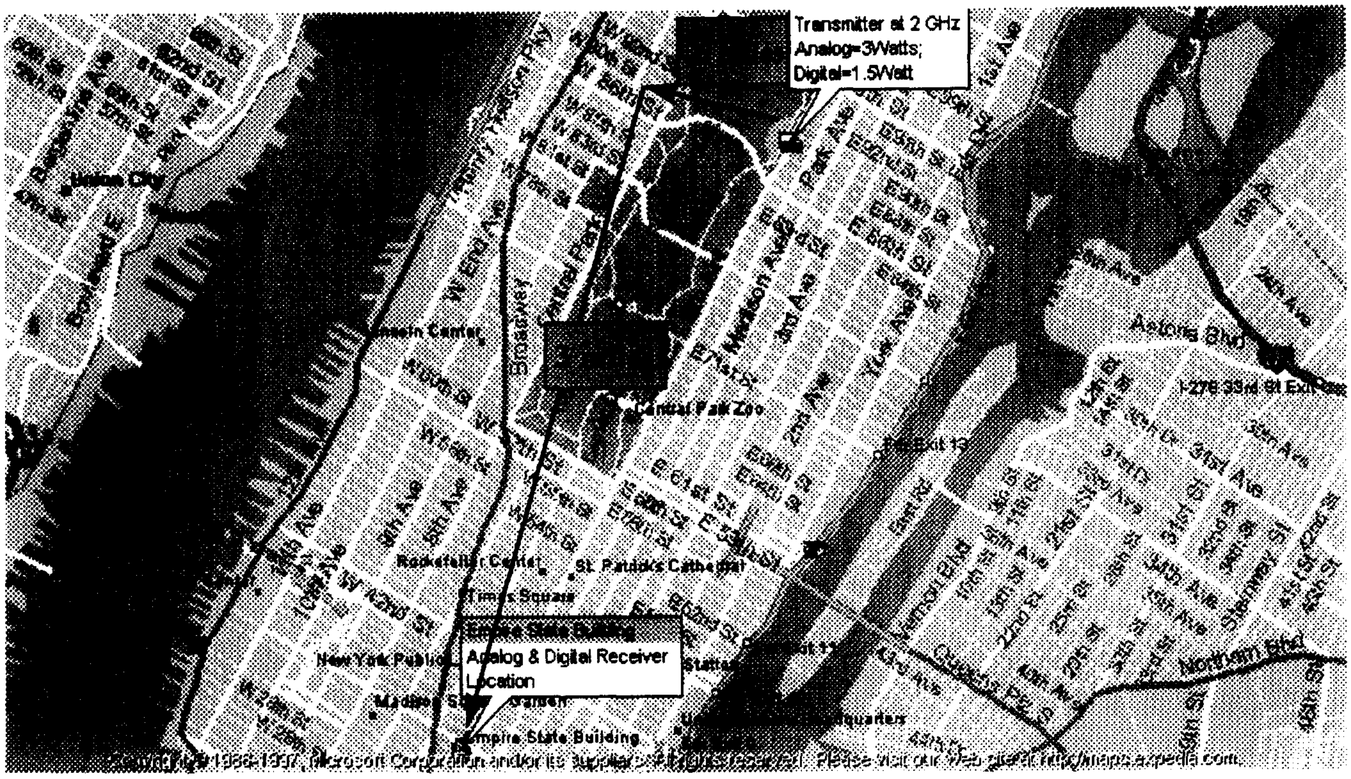
Case 3: Extreme multi-path (~ 90 degree Bounce Shot)



Unusable / Weak Analog Signal
Very Good Digital Picture

Figure 13

Test Results for Case 3: Extreme multi-path

Mode	Bit Rate	FEC	BW	Rcv. Signal Level
Analog FM			17 MHz	-70 dBm
Digital	9 Mbps	3/4	8.5 MHz	-74 dBm
	10.5 Mbps	7/8	8.5 MHz	-74 dBm
	12.5 Mbps	3/4	12 MHz	-73 dBm
	15 Mbps	7/8	12 MHz	-73 dBm
	8 Mbps	2/3	8.5 MHz	-72 dBm
	6 Mbps	1/2	8.5 MHz	-72 dBm
	4.5 Mbps	3/4	4.5 MHz	-74 dBm
	4.5 Mbps	1/2	6.5 MHz	-72 dBm

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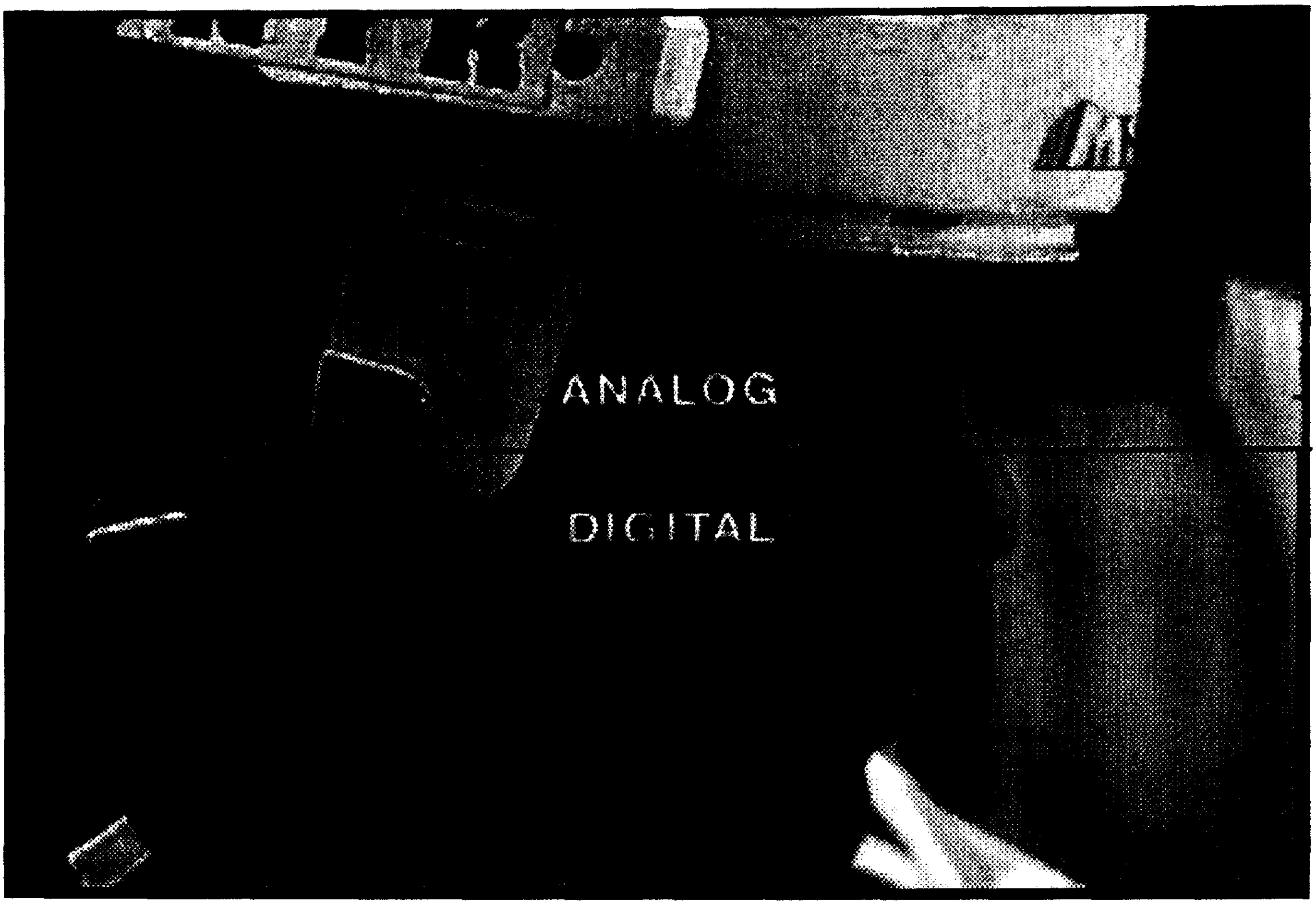
Picture Quality of Analog vs. Digital (9 Mbps, 3/4 FEC) Transmission for Case 3: Extreme multi-path

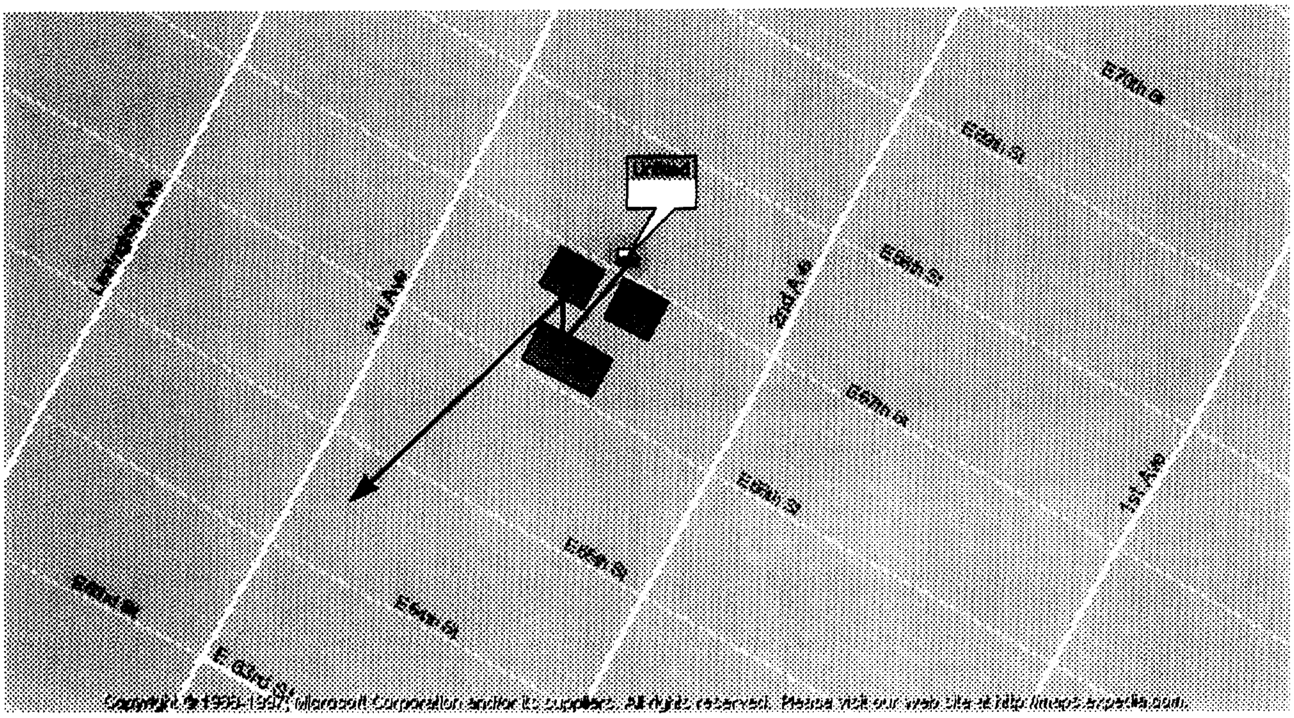


Test Case 4:

A fourth test shot was performed from in front of the WNYW studio as shown in the map of Figure 14. The Empire State Building was not visible from this location. Line of sight was blocked by numerous high rise buildings. The shot was blindly established by panning the antenna so as to shoot down an alley between two tall building and reflecting the signal off at least two other buildings. The resultant analog picture was both suitable for broadcasting. When the digital signal was transmitted, a perfect picture was consistently received.

The results of these tests, which pleasantly surprised all concerned, clearly show that Digital Video, when used for ENG in the 2 GHz band, consistently produces a picture equal to and in most cases superior to the analog transmission system.

ENG Double Bounce Shot



Results -Very Noisy Analog with Multi-Path Perfect Digital Signal

Figure 14

Summary

- **Digital transmission makes more efficient use of frequency spectrum**
  - ~8.5 MHz bandwidth as compared to 17 MHz analog (approximately double efficiency)
- **Digital transmission provides cleaner signal**
  - no ghosting artifacts
- **Digital transmission provides a superior signal in multi-path environments**
  - digital transmission allows employing techniques such as forwar error correction to provide a more robust signal over analog transmission
  - ETC...

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Conclusions:

We have presented:

- an overview of how the Digital Video Microwave technology will be applied to STL and ENG systems,
- actual laboratory and field results of tests conducted by NUCOMM using Digital Video Microwave Systems in STL and ENG applications.

These tests show that applying digital video compression, QPSK modulation, and forward error correction for STL and ENG systems can conserves frequency spectrum and yields superior video and audio quality and performance equal to and better than analog systems under both fading and multi-path environments. The digital ENG field tests specifically showed that an encoding rate of 9 Mbps yielded sufficient audio and video quality and a forward error correction rate of ¾ provided adequate error protection for all the test cases including extreme multipath interference even when using demanding source material, such as the hockey game sequence. This combination (9 Mbps, ¾ FEC) not only resulted in superior video and audio quality but also required only half the analog FM transmission bandwidths.. Higher order modulation codes for STL to conserve spectrum is advisable. Further tests are needed. The use of 16QAM modulation for ENG needs further testing. However, this and higher order codes will be more susceptible to multi-path and other interference.

The tests were performed without the use of adaptive equalization in the Digital Demodulators. Equalization was purposely not used so as to measure the uncorrected multi-path effects on such a system. The use of adaptive equalization can only further improve the performance of Digital Video systems. Further tests are planned using 16QAM and adaptive equalization.

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